# KamLAND sees Spectral Distortions in Neutrino Oscillation

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The KamLAND experiment is a reactor neutrino experiment situated in a mine in western Japan. The goal of the experiment is to measure neutrino oscillation in the (1,2) channel using anti-neutrinos. The flux-weighted average distance from the KamLAND detector to the 53 Japanese commercial power reactors, the source of the electron anti-neutrinos ($\overline{\nu}_e$), is $\sim$175 km. KamLAND reported on the first reactor neutrino oscillation measurement, with 162-ton-yr of exposure, in Ref. [1].

Recently, KamLAND published an analysis of a 766-ton-yr exposure to reactor anti-neutrinos [2] showing spectral distortion in the neutrino spectrum, see fig. 1. Distortions in the energy spectrum are expected in case of neutrino oscillation and are a clear signature of the energy-dependent oscillation effect; KamLAND observes this distortion. A statistical analysis shows that the data disagrees with a simple re-scaling of the reactor spectrum at 99.6% statistical significance. Furthermore, a hypothesis test reveals that neutrino oscillation is strongly preferred, while alternative anti-neutrino disappearance scenarios, such as neutrino decay or quantum mechanical decoherence, are excluded at >98% C.L. The KamLAND spectral distortion result together with solar neutrino fluxes and under the assumption of CPT, dramatically shrink the region of the possible value of the mass splitting in the (1,2) channel, see fig. 2. A global analysis of data from KamLAND and solar neutrino experiments yields $\Delta m^2_{12} = 7.9^{+0.6}_{-0.5} \times 10^{-5}\,\mathrm{eV}^2$ and $\tan^2\theta_{12} = 0.40^{+0.10}_{-0.07}$. This result is the most precise determination of the $\Delta m^2_{12}$ value to date.

During the analysis of the expanded reactor data set, a new background was discovered. This background comes indirectly from the $\alpha$-decays of the radon daughter $^{210}$Po in the liquid scintillator. The 5.3 MeV $\alpha$-particle is quenched below the trigger threshold of 0.9 MeV, but the secondary reaction $^{13}$C($\alpha$,n)$^{16}$O produces events above the trigger threshold. The reactor neutrino analysis threshold is 2.6 MeV prompt energy and for the second reactor result [2] the background is estimated to be 10.3±7.1 events, almost twice as large as the other background contributions combined. However, the background from the ($\alpha$,n) reaction is considerable below 2.6 MeV, the region of interest for a search of geologically produced anti-neutrinos (geoneutrinos) and will impact KamLAND's ability to measure geoneutrinos precisely.

The current KamLAND reactor $\overline{\nu}_e$ analysis focusses on a further reduction of the systematic uncertainties. To this end, LBNL is developing a full volume calibration system which will be deployed in the fall of 2005.

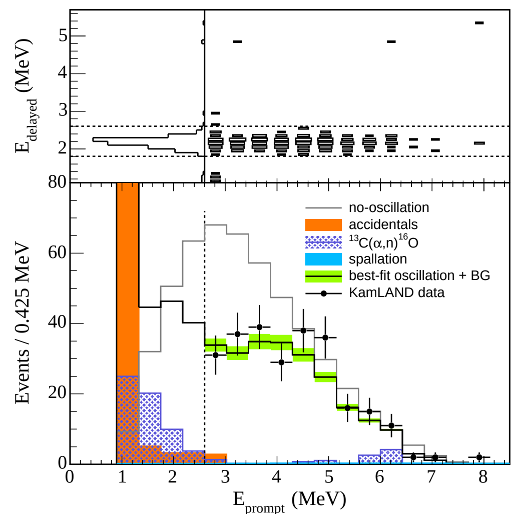


FIG. 1: (top)The correlation of energies between the prompt and delayed events after cuts. The events between the two dashed lines and above 2.6 MeV are the reactor $\overline{\nu}_e$ candidates. (bottom) The prompt event energy spectrum of the $\overline{\nu}_e$ candidate events along with the background spectra [2]. The best-fit oscillation spectrum is strongly preferred over a (scaled) no-oscillation spectrum.

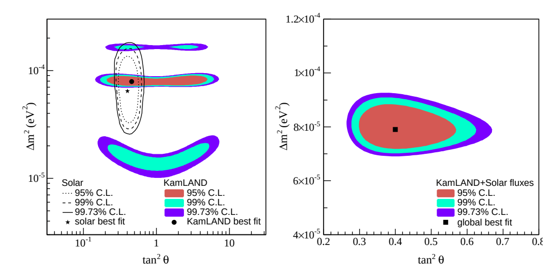


FIG. 2: (left) Neutrino oscillation parameter allowed region from KamLAND anti-neutrino data (shaded regions) and solar neutrino experiments (lines). (right) Result of a combined two-neutrino oscillation analysis of KamLAND and observed solar neutrino fluxes under the assumption of CPT invariance. The fit gives $\Delta m^2_{12} = 7.9^{+0.6}_{-0.5} \times 10^{-5}\,\mathrm{eV}^2$ and $\tan^2\theta_{12} = 0.40^{+0.10}_{-0.07}$ including the allowed 1-sigma parameter range.

[1] K. Eguchi *et al.* [KamLAND Collaboration], Phys. Rev. Lett. **90**, 021802 (2003).

[2] T. Araki *et al.* [KamLAND Collaboration] Phys. Rev. Lett. **94**, 081801 (2004), [arXiv:hep-ex/0406035].